MCR-95-506

Issue 1

Scientific and Technical Progress Report

April 1995

Intelligent Manufacturing of Layered Photovoltaics Program

Contract Number N00014-95-C-0004

Contract Data Requirement List Item Number A001

Martin Marietta Technologies, Inc.
P.O. Box 179
Denver, Colorado 80201-0179

Quarterly Report
for
Intelligent Manufacturing
of
Layered Photovoltaics

April 1995

Submitted by
Dr. M.E. Jackson
Lockheed Martin Astronautics Company
PO Box 179, MS-F3085
Denver CO 80201

1. Introduction

1.1 Background

The development team at Lockheed Martin will use the Advanced Intelligent Manufacturing technique to develop the Intelligent Processing for $CuInSe_2$ (CIS) manufacture[1].

1.2 Scope

The purpose of IMLP is to provide the Intelligent Processing for the CIS material process development. Figure 1 below shows the overall process flow.

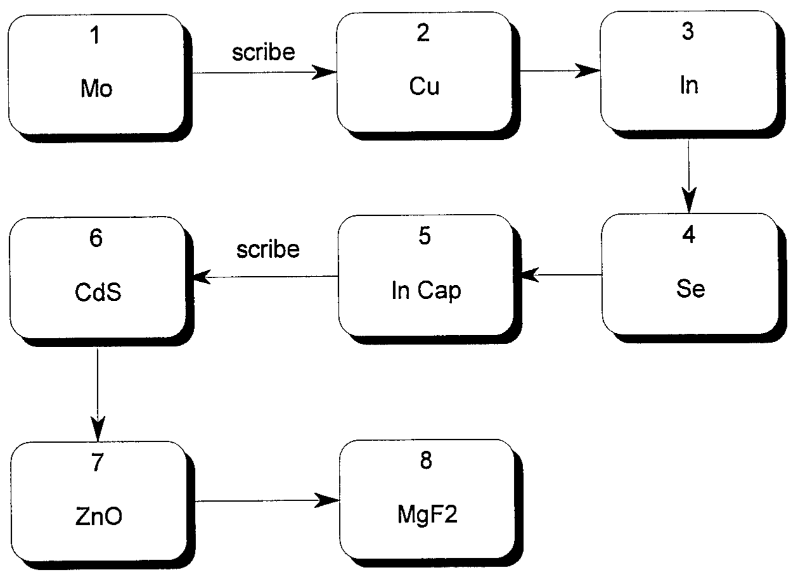

Figure 1. Overall Process Flow for CIS

The scope of the effort is the development of physically faithful process control models that produce high quality CIS.

1.3 Approach

The approach for this effort is to decompose the process into major components as shown in Figure 2 below.

---

[1] M.E. Jackson, "Develop Automated Intelligent Manufacturing for the External Tank," Martin Marietta Michoud Aerospace, NASA Technical Directive 1.6.2.1-673-R3-4, (1989).

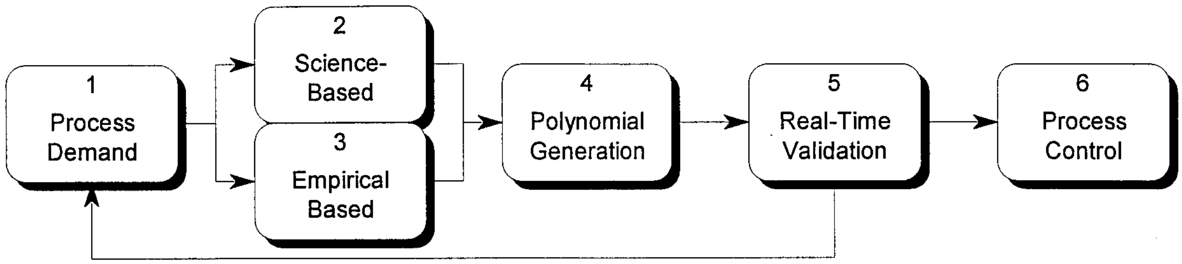

Figure 2. Major Components of a Process Control Model

Component 1 is the Process Demand that is the specific requirement. Component 2 is the science-based model that estimates the response based upon the demand and the physically faithful model that simulates the process. The third major component is based upon physical, directly measured process response against known stimuli. Using a Designed Experimental approach, one minimizes physical numbers of data while maximizing the available process envelope. The fourth component is an n^{th} order, n-dimensional polynomial whose inputs are those components to the left including middle elements chosen for their utility by the engineer and whose outputs correlate all inputs against the physical process and real-time process information. Component 5 is the brute-force component that ensures that the delta between process demand and process control code equals zero, results in component 6, Process Control.

Process Demand is a simple requirement request such as desired film thickness. The science-based model is an attempt to estimate the required process extents that will yield the process demand. This model is based upon known, physical parameters. The empirical model is a set of data that represents process stimuli and the physically measured process parameters. It should be clear that empirical data can be readily used to predict behavior within the tolerance band of the polynomial that the empirical data describes. The polynomial generation step is a harsh mathematical collation of the outputs, weighted by inspection, of the science and empirical-based models used to generate the coefficients for a large polynomial control equation. This control equation produces highly proportional and quite accurate parameter offsets used to force the process to meet the process demand. The advantages of using a polynomial to implement the results of science and empirical-based models are that their coefficients can be continually updated with each successful process run producing increasingly better results. The last step in producing real-time, intelligent processing control is the real-time validation of the measured results of the control law and forcing the process to meet the process demand. Any required offsets at this step can be used to upgrade the empirical model and the coefficients for the control polynomial.

The output of the IMLP contract is to develop reproducible, physically faithful process control for the large-scale production of CIS.

1.4 Expected Results

It is expected that CIS will be produced in hiqh quality amounts using these advanced, automated techniques. Science-based modeling provides the underlying framework upon which the overall process control will be correlated with the processing equipment.

2. Statement of Work

2.1 Program

The program Tasks are depicted in the following Figure 3.

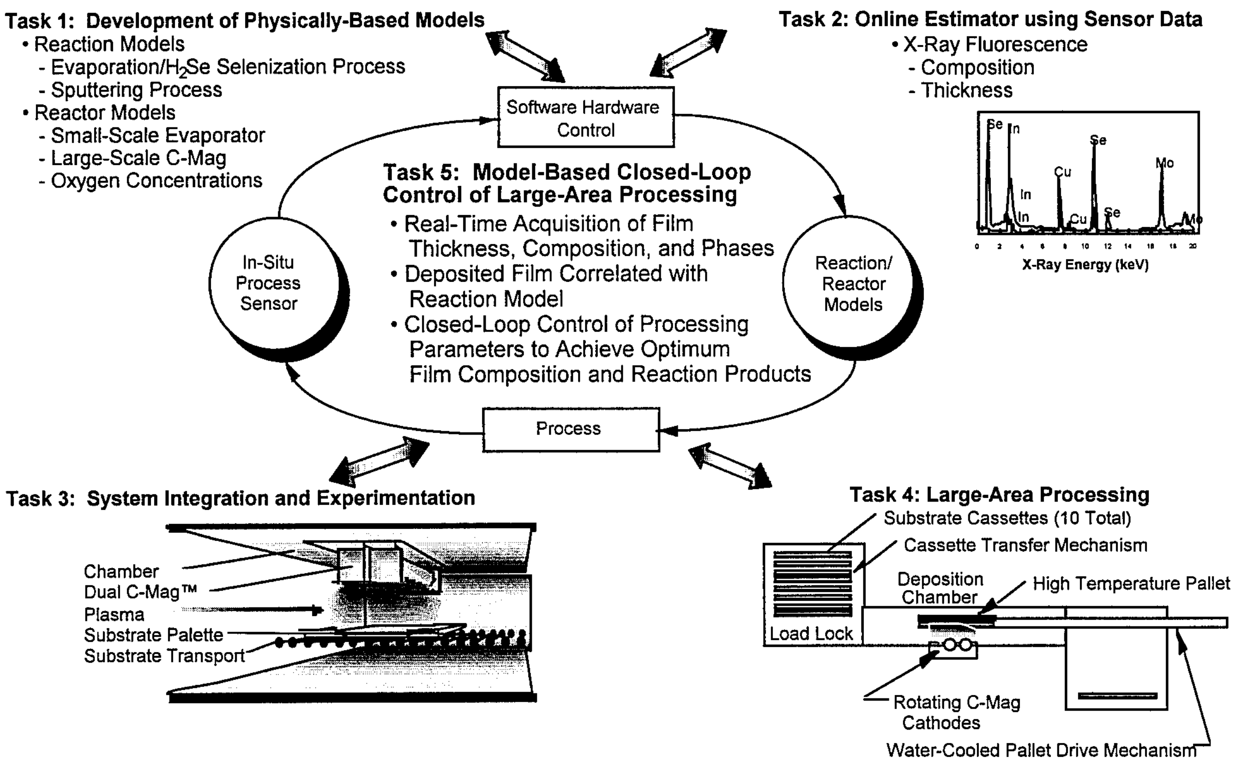

Figure 3. IMLP Task List

The program Statement of Work is depicted in the following Figure 4.

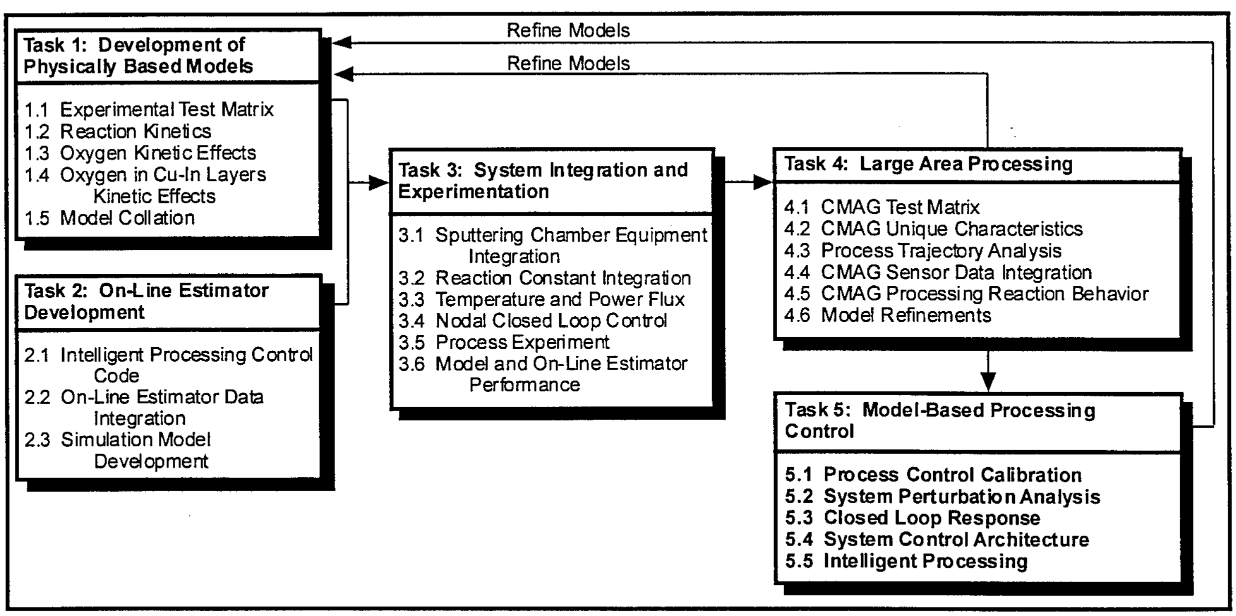

Figure 4. Statement of Work

3. Approach

The basic option for the IMLP contract develops the fundamental tools required for the large-scale production of CIS. These tools are generated by

- Dr. R. Birkmire, Institute of Energy Conversion (IEC), University of Delaware
    - THIN-FILM REACTOR SYSTEM
        - Identify and establish fundamental balances for a complete thin-film reactor system (i.e., mass, energy, and momentum; flux in/flux out); establish relationships for a known reactor system, such as evaporation, and clearly state all assumptions).
    - MEASURABLE PARAMETERS
        - Identify all measurable parameters in the basic science based models, how these parameters will be measured (tolerances, accuracy, etc.), and how these parameters relate to the fundamental model equations.
    - PARAMETER INCORPORATION
        - Using known parameters and data from an example system (i.e., H2Se), demonstrate how these parameters are incorporated into the model; show how these parameters can be used to control film properties. In addition, comment on how well these parameters can control the system and the relationship of these parameters to device performance (i.e., first-order, second-order effects).

EXPERIMENTAL VERIFICATIONDevise experimental set-up and hardware to validate control methodology of proposed model system; test, if possible, real time control of CIS reactor.Dr. T.H. Ridgway, University of Cincinnati

- Coordinate with IEC in the development of process models.
- Develop science based algorithms based upon IEC's models and data.
- Develop software code suitable for integration with Intelligent Processing control code.

- Dr. M.E. Jackson, Lockheed Martin Astronautics Company
    - Develop Temperature Controller for the LMAC CMAG research chamber.
    - Develop EDS Controller for the LMAC CMAG research chamber.
    - Develop the Logistical Controller for the LMAC research chamber.
    - Acquire the data for the empirical model.

- Integrate the results from IEC and UC.
- Develop the real-time validation methodology for the IEC, UC, and LMAC results.
- Develop and refine the polynomial generator for the Intelligent Processing of CIS.
- Design hardware and software system for integration at the IEC laboratories to accomplish IEC's Task 4.

4. Results

4.1 Physically-Based Modeling

On April 6, 1995, an integration meeting was held by Lockheed Martin with IEC and the University of Cincinnati to scope the implementation plan for the Intelligent Processing for IMLP. Using the wealth of data from IEC, the mathematical capabilities of UC, and the practical integration capabilities of Lockheed Martin, the physically-based model for the production of CIS was outlined and will be completed by April 14, 1995. This model will then be used to baseline all further developments and to provide a common semantical background for all participants. The details of the baselined CIS model will be available during the monthly report May 1995.

4.2 Intelligent Processing

The Intelligent Processing task is composed of several parts.

- Implementation Tools
    - Basic Equipment Controls
    - Empirical Data Generation
    - Equipment Correlation Polynomial Generation
- Models Integration
- Intelligent Processing Testing and Refinement

The equipment controls are basically in place. The connection to the logistics controller is currently being worked. When the new power supplies are installed, empirical data generation will be performed. The initial CIS science-based model will be ready for encoding by the end of May. This model will be used to generate the input parameters for the generation of empirical data. A Finite Difference Simulator will be used to give a clearer picture for model refinement.

OFFICE OF THE UNDER SECRETARY OF DEFENSE (ACQUISITION)
DEFENSE TECHNICAL INFORMATION CENTER
CAMERON STATION
ALEXANDRIA, VIRGINIA 22304-6145

IN REPLY REFER TO DTIC-OCC

SUBJECT: Distribution Statements on Technical Documents

TO: OFFICE OF NAVAL RESEARCH
CORPORATE PROGRAMS DIVISION
ONR 353
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5660

1995 1087 017

1. Reference: DoD Directive 5230.24, Distribution Statements on Technical Documents, 18 Mar 87.

2. The Defense Technical Information Center received the enclosed report (referenced below) which is not marked in accordance with the above reference.

TECH PROGRESS REPORT
N00014-95-C-0004
TITLE: INTELLIGENT
MANUFACTURING OF LAYERED
PHOTOVOLTAICS PROGRAM

3. We request the appropriate distribution statement be assigned and the report returned to DTIC within 5 working days.

4. Approved distribution statements are listed on the reverse of this letter. If you have any questions regarding these statements, call DTIC's Cataloging Branch, (703) 274-6837.

FOR THE ADMINISTRATOR:

GOPALAKRISHNAN NAIR
Chief, Cataloging Branch

1 Encl

FL-171
Jul 93

DISTRIBUTION STATEMENT A:

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

DISTRIBUTION STATEMENT B:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES ONLY; (Indicate Reason and Date Below). OTHER REQUESTS FOR THIS DOCUMENT SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT C:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES AND THEIR CONTRACTORS; (Indicate Reason and Date Below). OTHER REQUESTS FOR THIS DOCUMENT SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT D:

DISTRIBUTION AUTHORIZED TO DOD AND U.S. DOD CONTRACTORS ONLY; (Indicate Reason and Date Below). OTHER REQUESTS SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT E:

DISTRIBUTION AUTHORIZED TO DOD COMPONENTS ONLY; (Indicate Reason and Date Below). OTHER REQUESTS SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT F:

FURTHER DISSEMINATION ONLY AS DIRECTED BY (Indicate Controlling DoD Office and Date Below) or HIGHER DOD AUTHORITY.

DISTRIBUTION STATEMENT X:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES AND PRIVATE INDIVIDUALS OR ENTERPRISES ELIGIBLE TO OBTAIN EXPORT-CONTROLLED TECHNICAL DATA IN ACCORDANCE WITH DOD DIRECTIVE 5230.25, WITHHOLDING OF UNCLASSIFIED TECHNICAL DATA FROM PUBLIC DISCLOSURE, 6 Nov 1984 (Indicate date of determination). CONTROLLING DOD OFFICE IS (Indicate Controlling DoD Office).

The cited documents has been reviewed by competent authority and the following distribution statement is hereby authorized.

A
(Statement)

OFFICE OF NAVAL RESEARCH
CORPORATE PROGRAMS DIVISION
ONR 353
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5660

(Controlling DoD Office Name)

(Reason)

(Controlling DoD Office Address, City, State, Zip)

DEBRA T. HUGHES
DEPUTY DIRECTOR
CORPORATE PROGRAMS OFFICE

(Signature & Typed Name) (Assigning Office)

25 SEP 1995

(Date Statement Assigned)